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16. ABSTRACT

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MARSH PLANTS AS VECTORS IN TRACE METAL TRANSPORT IN OREGON TIDAL MARSHES[1]

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ABSTRACT

The role of Pacific coast marsh plants as vectors in the flux of trace metals was studied in natural and perturbated situations. The flux of Cr, Cu, Fe, Mg, Sr, and Zn were studied in natural stands of *Carex lyngbyei*, *Distichlis spicata*, *Potentilla pacifica*, and *Salicornia virginica*. Seasonal fluxes of trace metals into the shoots of the living plants were measured as was their transfer to the dead plant community through mortality. Disappearance from the latter community (through fragmentation, leaching and excretion) was calculated. Seasonal data were summed to produce annual input-output budgets. The flux varied from 3 mg/m² for Cr in a stand of *Potentilla pacifica* to 15,000 mg/m² for Fe in *Carex lyngbyei*.

The uptake of trace metals from contaminated dredged material was compared with that from natural soils using modified buckets placed in the marsh. Four plants (*Carex lyngbyei*, *Distichlis spicata*, *Deschampsia cespitosa*, and *Salicornia virginica*) were tested for Cd, Cr, Cu, Pb and Zn. Copper was the only metal accumulated from contaminated soils in the situations tested.

NORTH AMERICAN PACIFIC coastal marshes are generally small compared to those associated with most Atlantic and Gulf of Mexico shores. On the western coast, the land and sea meet in a steep topographic gradient and the intertidal zone is small. The Pacific coast is an especially high energy zone and marshes can develop only in very protected embayments. Three general types of setting can be identified where salt marshes develop: 1) *Island or peninsular river deltas*; in these estuaries a marshy delta develops in the lee of an island or peninsula. The Frazer River delta marshlands behind Vancouver Island in British Columbia and those along the Matanuska River in Alaska, which empties into Cook Inlet, are examples of these types. 2) *Baymouth bar protected embayments*; the protection for the marshland development in these areas comes from a sand spit formed by longshore drift enclosing an embayment. Some bays of this size, such as Humbolt Bay in California or Netarts Bay in Oregon, have little freshwater input and are nearly marine in nature. Others such as Siletz Bay in Oregon are substantially influenced by the rivers associated with them. 3) *Riverine estuaries*; some rivers which flow more or less directly into the Pacific without first entering embayments have extensive fringing marshes. These may be large like the Columbia River estuary between Oregon and Washington or small such as the Siuslaw River estuary in Oregon. Typically a shallow bar forms at the mouth and dissipates the major wave energy before it reaches the estuary.

As in the Atlantic and Gulf coast areas, the nature of the soils in the marshes depends on the sediment load in the water entering the marsh rather than the original substrate. In general the marshes of the Pacific coast are associated with emerging coastal areas. Sediments are deposited on intertidal bars and flats elevating them to a position where emergent macrophytes can colonize. The stems of the plants act as filters to trap sediment more efficiently and elevate the surface more rapidly. On the Oregon coast, where we have concentrated our efforts, *Scirpus americanus* Pers., *Salicornia virginica* L. and *Triglochin maritimum* L. are typical of the primary colonizers. The latter two persist through somewhat higher elevations. *S. virginica* often is found in mixed swards with *Distichlis spicata* (L.) (Greene) and *T. maritimum*, the latter tending to maintain the circular colonies which typified its initial colonization. In somewhat less saline environments, broad zones of *Carex lyngbyei* Hornem. may occupy these areas. At the highest elevations under regular tidal influence, communities of *Deschampsia cespitosa* L.

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TABLE 1. *Concentration (mg/kg dry weight) of trace metals in Juncus balticus in an Oregon marsh*[a]

Tissue	Season	Metal					
		Cr	Cu	Fe	Mn	Sr	Zn
Live	W	4 (2)	16 (2)	1,200 (300)	70 (2)	18 (2)	33 (1)
	S	1 (0)	6 (0)	100 (0)	107 (16)	23 (1)	26 (2)
	F	2 (0)	5 (0)	300 (100)	77 (12)	29 (1)	29 (4)
Dead	W	17 (4)	10 (2)	6,300 (1,400)	593 (125)	68 (4)	44 (1)
	S	6 (1)	9 (1)	1,700 (200)	159 (10)	69 (3)	35 (5)
	F	12 (3)	14 (2)	2,700 (1,600)	256 (35)	59 (9)	42 (4)

[a] Numbers in parenthesis are standard errors (n = 3) W—winter, S—summer, F—fall.

Beauv., *Juncus balticus* Willd. and *Agrostis alba* L. develop. In addition to the sediment trapping role of the plant shoots in marsh soil formation, the organic input of the roots greatly influences soil development. In areas of rapid sedimentation, or at least rapid resuspension and deposition such as the Frazer River in British Columbia or the Turnagin arm of Cook Inlet, the soils are primarily mineral in nature, at least in the upper 10–15 cm. Soils are very peaty in marshes developed in areas with little sediment input. These differences undoubtedly greatly influence the nature of the soil phase of trace metal cycling in these systems.

The food web in these marshes as in Atlantic coastal marshes is primarily detritus based. Macrofauna, which are so prominent in mid Atlantic and south Atlantic marshes, are scarce in the Pacific Northwest. Microbes, insects and amphipods appear to be the most important heterotrophs on the Pacific coast marsh. Once detrital material leaves the attached 'dead plant community' (dead plants plus the community of microorganisms), the food web in the Northwest marshes probably includes copepods, mollusks and salmonid fishes (Sibert, 1977).

Our research into trace metal cycling in Pacific coast estuaries has focused on answering two questions about the role of marsh plants: 1) What are the natural cycles of transfer of these trace metals: a) into the living plant, b) from the living plants to the dead plants through mortality and, c) from the attached 'dead plant community' to the rest of the ecosystem via fragmentation, leaching and excretion? 2) Are there differences in the effectiveness of various plants in the natural marsh to act as vectors for the transfer of trace metals from contaminated sediments into the aerial parts of the plant and hence into the food chains?

METHODS AND MATERIALS—Our approach to answering the first question was to couple seasonal metal concentrations in plant tissues with estimates of d v matter production and disappearance made by measuring live biomass, dead biomass and mortality. Trace metal concentrations were measured on tissue dried to a constant weight at 60 C and ground in a Wiley mill to pass a 40-mesh screen. Analyses were done using an inductively coupled plasma emission spectrometer (Applied Research Laboratories) on samples which had been digested with nitric and perchloric acid on a Technicon block digester.

Live and dead biomass measurements in each stand were made by harvesting the plants in seven randomly placed quadrat frames at 8-wk intervals during winter and 6-wk intervals during other times of the year. Mortality was measured in similar plots by the method described by Lomnicki, Bandala and Jankowska (1968). Quadrats 0.1 m^2, 0.05 m^2, 0.025 m^2 and 0.25 m^2 were used in stands of *Carex lyngbyei*, *Potentilla pacifica*, *Salicornia virginica*, and *Juncus balticus* respectively. The studies with *Carex lyngbyei* were done in a marsh at Siletz Bay and those with the other species in a marsh bordering Netarts Bay. All plant nomenclature is based on Hitchcock and Cronquist (1973).

The approach to the second question was experimental. Twelve plastic buckets, modified by drilling 150 3-mm holes in the sides and bottom, were filled to within 3 cm of the lip with dredged material contaminated with trace metals. Three buckets were dug into the marsh in each of four plant stands, *Carex lyngbyei*, *Deschampsia cespitosa*, *Distichlis spicata*, and *Salicornia virginica*. The buckets were placed at a depth so that the surface of the marsh and the dredged material were even. Several notches then were cut in the bucket lip to allow free movement of water between the surfaces of the marsh and dredged material. Similar buckets were filled with natural uncontaminated soil from the plant stands and placed in the marsh near the buckets containing contaminated material. Each bucket was planted with sprigs from marsh soil removed for bucket implantation. After 8 wk of growth live plants were harvested. Each leaf was washed

TABLE 2. *Annual mean concentration (mg/kg dry weight) of trace metals in marsh plants in Oregon (N = 9)*

		Metal					
	Tissue	Cr	Cu	Fe	Mn	Sr	Zn
Carex lyngbyei	live	9	10	2,400	341	28	45
	dead	33	16	12,800	343	67	62
Salicornia virginica	live	10	13	3,100	196	62	60
	dead	16	12	4,900	310	114	39
Juncus balticus	live	2	9	500	85	24	29
	dead	6	11	3,600	336	65	40
Potentilla pacifica	live	3	8	100	30	200	41
	dead	6	10	800	52	260	58
species	live	2–10	8–13	100–2,400	30–341	24–200	27–60
range	dead	6–33	1–16	800–12,800	52–343	65–260	39–62

3 times with distilled water and wiped with a Kimwipe. Following three washings and wipings with methanol, the distilled water washings were repeated. Next, each leaf was washed with a 1N HCl solution and then wiped. Four more washings and wipings with distilled water completed the cleaning procedure. Plants were then dried at 60 C and ground to pass a 40-mesh screen. After total digestion by the method described for potassium and sodium in Black (1965), the digested samples were analyzed with an argon plasma emission spectrometer. Soils collected from the natural plant stands and the contaminated dredged material were analyzed in a similar fashion.

RESULTS AND DISCUSSION—A summary of seasonal concentration changes in the trace metals in live and dead *J. balticus* is shown in Table 1. The consistently higher concentrations of metals in dead plant material may be due to one or a combination of several factors. First, these tissues are more porous than the live and hence interstitial spaces may be more readily contaminated with sediment. Second, the same porous structure may provide surfaces for sorption of salts from the flooding seawater. Third, decomposition may be selectively removing other components. Fourth, microbes may be associated with the dead plants resulting in the precipitation of metals in tissue. With only a few exceptions, the summer trace metal values are the lowest. This may be due to dilution associated with the rapid spring and summer growth.

In Table 2 is a summary of the mean annual concentration on metals in the four species. The ranges in trace metal concentration between species is also shown in Table 2. With the exception of Fe in dead *C. lyngbyei*, the ranges in live and dead material are similar. The dead plant was generally higher in trace metal concentration. Williams and Murdock (1969) also observed that metals were more concentrated in dead than living tissue.

We then coupled these concentration data with the live biomass, dead biomass and mortality data to calculate three fluxes in the conceptual model in Fig. 1, as follows: 1) Uptake—the transfer from the marsh substrate to live shoot includes both current transfers from soil through roots to shoots and those coming from metals stored in below ground plant parts. 2) Mortality—transfers via this means begin the flow through the detrital food web. We calculated this flux using mortality measurements

TABLE 3. *Annual trace metal uptake by live marsh plant shoots and loss from the dead plant shoot community. U—uptake, F—fragmentation, leaching, excretion*

		Plant species							
		Carex lyngbyei		*Juncus balticus*		*Potentilla pacifica*		*Salicornia virginica*	
Trace metal	Units per m²	U	F	U	F	U	F	U	F
Cr	mg	38	39	6.0	7.0	3.0	3.0	16.0	18.0
Cu	mg	20	18	5.0	7.0	6.0	6.0	15.0	15.0
Fe	g	14	15	1.7	2.0	0.4	0.4	4.5	5.2
Mn	mg	655	676	161.0	191.0	28.0	26.0	311.0	300.0
Sr	mg	76	75	33.0	31.0	113.0	143.0	122.0	124.0
Zn	mg	73	74	20.0	22.0	29.0	32.0	40.0	44.0

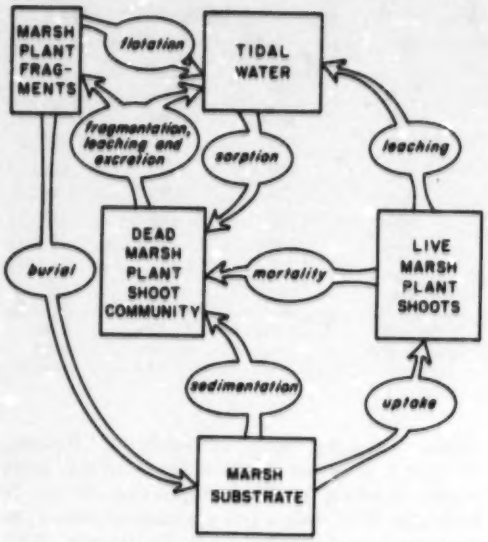

Fig. 1. Conceptual model of the role of marsh plants as vectors in trace metal dynamics.

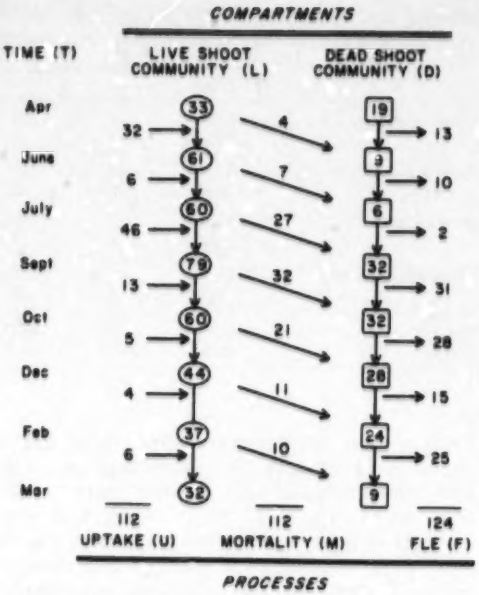

Fig. 2. Flow chart of the flux of strontium through live *Salicornia virginica* and the community associated with the attached dead plants.

and the concentration of metals in the dead tissue. 3) Fragmentation, leaching and excretion—this complex of processes included losses which involved passive leaching of metals from the attached dead plants, excretion by the organisms associated with that community and fragmentation. We have not discriminated among these components. We do know, however, that dissolved organic carbon (DOC) release from dead marsh plants is a small percentage of the total carbon pool (Gallagher and Pfeiffer, 1977) and that some ions are released rapidly from both living and dead plant tissue (Reimold, 1972; Gallagher, 1975). We might expect K and similar elements that are only in ionic forms in cells to be released rapidly when the tissues die and the integrity of the cell membranes deteriorates. Much of their flux from the attached plant community would thus follow the leaching pathway rather than that of fragmentation. On the other hand, the fragmentation pathway might be more important for elements forming structural or storage compounds in plants.

A representative data set for trace metal flux is shown for Sr in *S. virginica* in Fig. 2. The uptake values were calculated using equation 1.

$$U = (L_{t2} - L_{t1}) + M_{t1t2} \qquad (1)$$

Uptake (U) equals the change in the metal in the living component ($L_{t2} - L_{t1}$) plus that lost to mortality (M_{t1t2}) during the time period. The most active movement of strontium into the living tissue was during rapid growth in the spring and summer. The uptake values for each time period were summed to give a yearly flux into the plants.

The output was calculated using aerial biomass data and equation 2.

TABLE 4. *Trace metal content (mg/kg dry weight) of natural Oregon marsh soils and a contaminated dredged material*

Substrate	Trace metal				
	Cd	Cr	Cu	Pb	Zn
Carex lyngbyei soil	0.220	114.0	94.3	8.09	101.0
Deschampsia cespitosa soil	0.168	98.9	9.1	8.61	38.7
Distichlis spicata soil	0.113	100.0	76.5	12.00	75.4
Salicornia virginica soil	0.540	87.4	86.9	13.10	85.8
Contaminated dredged material	42.000	3,980.0	4,720.0	798.00	3,390.0

TABLE 5. *Trace metal content (mg/kg dry weight) of plant material grown in natural Oregon marsh soil (nat) and contaminated dredged material (cont)*

Plant	Soil	Trace metal				
		Cd	Cr	Cu	Pb	Zn
Carex lyngbyei	nat	< 20.0	< 30.0	< 30.0	96.8	30.0
	cont	< 5.0	< 5.0	11.4	1.0	8.0
Deschampsia cespitosa	nat	< 5.0	< 5.0	10.0	2.2	23.3
	cont	< 5.0	< 5.0	15.2	14.0	10.0
Distichlis spicata	nat	< 5.0	< 5.0	7.1	3.2	27.7
	cont	< 5.0	9.0	36.3	2.0	28.2
Salicornia virginica	nat	< 5.0	< 5.0	7.9	2.8	19.9
	cont	< 5.0	6.4	34.7	6.6	38.1

$$F = [(MB_{t1t2} + DB_{t1}) - DB_{t2}]C_{D_{t1}} \quad (2)$$

Loss from the attached dead plant community (F) equals the biomass of plant material present at the beginning of the time period (DB_{t1}) plus that added to the dead plant community by mortality during the time period (MB_{t1t2}) less that present at the end (DB_{t2}). The resultant change in biomass was multiplied by the concentration ($C_{D_{t1}}$) of the trace metal in the dead plant community at t1 to give the output (F). The greatest loss of strontium from *S. virginica* occurs during the fall. Diagrams such as Fig. 2 were prepared for each trace metal for each of the four species of plants studied. The individual time period fluxes were summed to get annual uptake and loss figures which represent an estimate of the amount of the trace metals vectored through the marsh plants (Table 3). The input-output summations were corrected to account for difference in pool sizes between the beginning and end of the year. These form a natural data set with which trace metal cycling in contaminated areas might be compared.

We tested to see if there were differences in the effectiveness of various marsh plant species to act as vectors for the transfer of trace metals from contaminated sediments to the shoots of the plant and thereby into the food web. Table 4 contains data on the concentration of trace metals in the natural soils and the contaminated dredged material. Although there was some variation among the natural marsh soils they were all one to several orders of magnitude less than the contaminated dredged material.

The comparison of the control (natural soil) and the test (contaminated dredge material) plants is shown in Table 5. Although the Cd was, at the least, two orders of magnitude more abundant in the contaminated substrate, the concentration of the metal was not significantly higher in the test plants. Either the plants did not have the ability to absorb Cd or it was not in an available form. In contrast, Dunstan, Windom and McIntire (1975) found that, in laboratory studies, *Spartina alterniflora* accumulated Cd about 150 times that measured in natural samples. With the exception of Pb in *C. lyngbyei*, Cr, Pb or Zn concentrations were no higher in the plants grown on the dredged material than those planted in natural soils. The Pb values in *C. lyngbyei* appear to be anomalous, however; Dunstan et al. (1975) reported concentrations in *S. alterniflora* growing in Pb contaminated substrates were lower than for plants from natural soils. Copper was more concentrated in the *D. cespitosa*, *D. spicata* and *S. virginica* plants grown in contaminated sediment. Thus other members of the detrital food web would be exposed to higher than normal Cu concentrations. Eighteen months after the contaminated sediments were planted all of the plants had died. The mixture of heavy metals may have been too toxic for the plants to survive. This study has demonstrated what happened with a specific dredged material under a specific set of environmental conditions. Each set of marsh environmental conditions interacts with specific dredged material to produce a specific plant-sediment regime. A field bioassay such as that reported here, coupled with the seasonal data presented earlier, will enable the researcher to evaluate the potential impact of the addition of the contaminated dredged material to physical, chemical, biological milieu which constitutes the estuarine detrital food web.

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